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The cost benefit analysis and potential emission reduction evaluation of applying wall insulation for buildings in Malaysia

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ABSTRACT

Due to the rapidly increasing number of air-conditioned spaces in buildings, the electricity demand has significantly increased during the past decade in Malaysia. The present energy analysis attempts to predict the long term environmental impact of utilizing thermal insulation materials for exterior walls of Malaysian buildings. The optimum insulation thickness is mainly influenced by local electricity tariff rate, and the capital insulation outlays. In the present work, some of the commonly used insulators available in the Malaysian market were analyzed. The results show that 2.2 cm of fibreglass–urethane produces the largest cost savings, of around 1.863US$/m^2 and is the most economically feasible insulation material that reduces the annual CO_2 emission production level by 16.4 kg/m^2. The main focus of the survey is to predict the potential emission production fluctuation for over the next 20 years. In this regard, three different scenarios were introduced, based on different electricity production policies. It was revealed that the increase in the contribution of renewable power plants on one hand, and phasing out of the conventional thermal coal plants on the other will substantially lead to a diminished CO_2 emission in long term.

Contents

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Nomenclature

A	Area (m^2)
AC	Air conditioning
ADH	Annual degree demand hours
C_e	Electricity tariff (US$/kW h)
CO_2	Carbon dioxide
COP	Coefficient of performance
C_t	The annual total cost of energy per unit area (US$/$m^2$)
C_{ti}	Total insulation cost (US$/$m^2$)
C_v	Cost of insulation per unit volume (US$/$m^3$)
EF	Emission factor
EM	Emission production
FC	Fuel consumed
Hm	Highest maximum temperature
I	Inflation rate
K	Thermal conductivity
Lm	Lowest minimum temperature
Mdn	Mean daily minimum temperature
Mdx	Mean daily maximum temperature
N	Life cycle period
n	Year
$P(C_t)$	Present value of energy cost (US$/$m^2$)
PV	Present value (US$/$m^2$)
PWF	Present worth factor
Q	Heat transfer
RH	Relative humidity
R_w	Wall resistance
r	Discount rate
T_o/T_i	Outside/inside temperature
U	Overall heat transfer coefficient
X	Thickness

Subscripts

B	Masonry boards
ins	Insulation
opt	Optimum
W	Wall

1. Introduction

It is believed by researchers that global warming is the truth, caused mainly by human activities [1,2]. This is the result of a rapid rise in concentration of CO_2 and other greenhouse gases such as hydrocarbons, nitrogen oxide and volatile organic compounds in the atmosphere [3]. The concentration of greenhouse gases had started to increase since 1750, and it has a sharp rising trend in the year 1992 [4,5]. The warmest recorded decade was the 1990s and the warmest year was 1998 [6]. If this trend continues, it is predicted that the CO_2 emission will exceed 40 billion tons by the year 2030 [7]. On average, the residential sector consume around 20% of total energy and from this amount almost 57% is dedicated to indoor cooling or heating [8]. Any energy consumption reduction on this sector will directly lead to the decrease the fuel consumption and reduce the total emission production. Therefore, a wise strategy and a prompt action is required to be carried out in order to reduce the rate of emission production worldwide. At the same time, this goal should be met without sacrificing the living standard.

Dincer and Rosen [9] show that around half of the greenhouse effect is contributed by CO_2 accumulation in the atmosphere. If the current trend continues until the end of this century, the possibility of a massive climate change is high [10]. One possible way to undermine this tragedy is to control and reduce the electricity consumption by applying an insulation layer in the building's wall. One of the well-known traditions to reduce energy consumption of an AC system is to install an insulation layer on the external walls of the building [11]. It was found that wall and roof insulation can save up to 77% of energy consumption [12]. Hence, using a proper insulation material is considered as an effective means to reduce building electricity consumption and consequently can reduced the emission production level [13–15].

Nowadays, many different types of insulation materials with various thermal and physical properties are available in the market. However, the way they are used is different based on the wall/roof structure. There are number of works available in the literature that focus on the optimum insulation thickness. However, based on the author's knowledge, there is no work conducted on the long term emission reduction potential by utilizing different insulation materials on building walls in Malaysia. This work has specifically attempts to predict the emission reduction based on three different scenarios. Although the result of scenarios might have a significant diversion from the actual future, but regardless of how thing actually happened in the future, the results can give a clear picture to the policy makers that concern about the future of the planet earth.

2. Malaysia plan to reduce the emission

In order to reduce the level of emissions in the atmosphere, Malaysia has adopted the five-fuel diversification strategy energy mix since 1999. This energy mix is powered from five main sources, namely; crude oil, natural gas, coal/coke, hydropower and renewable energy [16]. However, renewable energy has yet to hold a significant part in the electricity production in Malaysia. The primary supply portion of each of the energy sources based on the available data from the year 1990 until 2008 is presented in Table 1. It can be observed that crude oil has the highest portion of more than 50% before the year 2008 followed by

Table 1
Primary energy sources and their share in Malaysia [17,18].

Energy source	Share in 1990 (%)	Share in 2005 (%)	Share in 2006 (%)	Share in 2008 (%)
Natural gas	27.9	28.0	28.9	43.4
Crude oil	61.1	62.0	59.7	38.2
Coal and coke	6.5	1.0	0.8	15.3
Hydropower	4.5	2.0	3.0	3.1

natural gas. The statistical data show that the crude oil share is remarkably decreasing and is gradually substituted by the natural gas. Hydropower has the lowest portion of less than 5% in providing electrical power and its share does not has a significant change during the past 20 years.

2.1. Metrological data

The required data for evaluating the optimum thermal insulation is collected from the Department of Statistics [19], Economic Planning Unit [20] and Ministry of Energy [21]. Meteorological data of six cities of Malaysia is presented in Table 2 [9]. The maximum and minimum temperatures were reported in Ipoh with 37 °C and in Kuantan with 16.8 °C, respectively. The occupied hours in commercial buildings is normally between 8 am and 5 pm, hence, the temperature and relative humidity (RH) in this period is considered during this study with the average temperature of 29 °C.

Generally, in Malaysia, the AC systems are to supply cold air with 25 °C and 40–60% RH inside the conditions space. Technological innovations in AC systems emphasizes on energy efficiency methods to downsize the AC system such as using reflective surfaces, thick walls, glazing and planting trees near the building.

2.2. Commonly used insulators

The thermal conductivity and cost of some of the commonly used thermal insulation materials that are available in the Malaysian market is tabulated in Table 3.

2.3. Electricity generation strategy

In the past decades, the electricity demand in the residential sector increased significantly, due to the growing number of high-rise buildings and increasing number of electrical applications. The electricity tariff rate in Malaysia based on the latest update, released by Tenaga National Berhad (TNB) (the main electricity provider in Malaysia) [22] is 0.078US$ per kW h. The composition of fuel consumption (mm^3 and ton) in Malaysian power plants from 2000 to 2008 is presented in Table 4 [23].

Table 2
Records of local cities temperatures and RH (year 2008).

City	24 hM°C	Mdx°C	Mdn°C	Hm°C	Lm°C	RH (%)
Kota Kinabalu	27	31.2	23.5	36	18.6	81.5
Senai	25.9	31.7	22.4	36	18.2	86.9
Subang	26.7	32.3	23	36.8	18.1	82.7
Ipoh	26.9	33	23.1	37	17.8	81.4
Bayan Lepas	27.2	31.3	23.8	36.3	18.7	82.2
Kota Bharu	26.8	31.2	32.5	36.5	18.3	82.2
Kuantan	26.1	31.6	22.7	36.9	16.8	85.4
Kuching	26.2	31.6	23	36.5	18.9	85.4

Table 3
Data of insulation materials.

Type of insulation	Thermal conductivity, K_{ins} (W/m °C)	Cost of insulation, ($/m^3)	Cost/K_{ins} ($ m °C/W m^3)
Fibreglass–urethane	0.021	214	10,190
Fiberglass (rigid)	0.033	304	9,212
Urethane (rigid)	0.024	262	10,917
Perlite	0.054	98	1,815
Extruded polystyrene	0.029	182	6,276
Urethane (roof deck)	0.021	221	10,524

Malaysia is accounted as a developing country and its population has been increasing in the recent years, on the other side the rate of electrical energy consumption was increasing thus, it the policies that promote renewable energies would not be failed. The government should invest on policies that lead to decrease in electricity demand such as social awareness and using absorption cooling systems [24].

3. The impact of using thermal insulation in the building envelope

A survey conducted by Dombayci [25] in Denizli, Turkey, shows that optimum insulation thickness of expanded polystyrene can decrease energy consumption by 46% and reduce CO_2 and SO_2 emissions around 42%, where coal was used as the fuel source. Çomakli and Yüksel [26] determined that CO_2 emissions can be decreased up to 50% by using optimum insulation thickness combined with other energy saving methods in buildings. Arslan and Kose [27] conducted their research on optimum insulation thickness on external walls considering the condensed vapor in existing buildings for Kutahya, Turkey. They found that by using insulation with a thickness of 6, 6.5 and 7.5 cm, the energy consumption will be reduced by 75%, 76% and 79%, respectively. Mahlia et al. [28] showed that applying an optimum insulation thickness with proper material will reduce the energy consumption considerably. Bolatturk [29] studied on 16 different locations in Turkey to investigate the optimum thickness of polystyrene. The results indicated that the best insulation thickness was in the range of 2 to 17 cm, with energy savings from 22% to 79%, and payback period from 1.3 to 4.5 years, depending on different locations. Gustafsson and Karlson [30] have investigated the effect of electricity tariff rate on optimum thickness of insulation. A recent investigation on optimum insulation thickness for Maldives was conducted by Mahlia and Iqbal [31], the results showed that by using optimum insulation thickness with proper air gaps, the energy consumption can be reduced by 66% to 77%. In Turkey it was found that the optimum insulation thicknesses vary between 1.06 and 7.64 cm and the energy savings vary between 19 and 47$/m^2 [32]. A recent study conducted by Ozel [33] show that by applying optimum insulation on the uninsulated walls, the annual fuel consumption can be reduced by 68% to 89.5% depending on insulation materials.

4. Determining the optimum thickness for thermal insulation

The Methodology used to evaluate the heat transfer through the wall and to investigate the optimum insulation thickness has been described in the author's previous investigation [23]. However, the details are demonstrated again for convenient reference.

4.1. Heat transfer

Heat can be transferred through the walls via conduction, convection and radiation. These phenomena may occur on their own or simultaneously. The conductive heat transfer (Q) is expressed as [31]:

$$Q = -\frac{KA\delta T}{\delta X} \tag{1}$$

where K is the conductivity constant. Fig. 1 shows the schematic drawing of the wall and the insulation layer. Assuming the wall has a thickness of X (m) and area of A (m^2) with outside and inside temperatures of T_o and T_i, respectively, and the temperature gradient through the wall is linear, the heat transfer per unit area can be

Table 4
Composition of fuel consumption (mm^3 and ton) in Malaysian power plants from 2000 to 2008.

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2000	Coal (kt)	2.99	–	–	–	2.99
	Natural gas	6286.38	2793.94	3221.59	–	12,301.91
	Fuel oil	0.60	–	–	–	0.60
	Diesel	–	0.18	–	0.02	0.21
2001	Coal (kton)	3.97	–	–	–	3.97
	Natural gas	6192.20	2796.00	3674.33	–	12,662.53
	Fuel oil	0.75	–	–	–	0.75
	Diesel	–	0.28	–	0.04	0.32
2002	Coal (kton)	5.07	–	–	–	5.07
	Natural gas	6175.32	2844.30	4198.00	–	13,217.62
	Fuel oil	1.39	–	–	–	1.40
	Diesel	–	0.47	–	0.06	0.53
2003	Coal (kton)	8.18	–	–	–	8.18
	Natural gas	3351.72	3047.02	5166.69	–	11,565.43
	Fuel oil	0.39	–	–	–	0.39
	Diesel	–	0.25	–	0.03	0.28
2004	Coal (kton)	10.61	–	–	–	10.61
	Natural gas	8365.17	989.43	1837.53	–	11,192.10
	Fuel oil	0.27	–	–	–	0.27
	Diesel	–	0.23	–	0.07	0.30
2005	Coal (kton)	10.99	–	–	–	10.99
	Natural gas	3503.99	3474.42	5987.83	–	12,966.24
	Fuel oil	0.20	–	–	–	0.20
	Diesel	–	0.41	–	0.03	0.44
2006	Coal (kton)	11.89	–	–	–	11.89
	Natural gas	4133.84	2432.55	6521.62	–	13,088.01
	Fuel oil	0.17	–	–	–	0.17
	Diesel	–	–	–	0.07	0.69
2007	Coal (kton)	14.93	–	–	–	14.94
	Natural gas	4784.99	2392.50	5988.67	–	13,166.16
	Fuel oil	0.20	–	–	–	0.20
	Diesel	–	0.31	–	0.03	0.34
2008	Coal (kton)	16.09	–	–	–	16.09
	Natural gas	5220.16	2675.74	5599.07	–	14,494.98
	Fuel oil	0.17	–	–	–	0.17
	Diesel	–	0.29	–	0.03	0.32

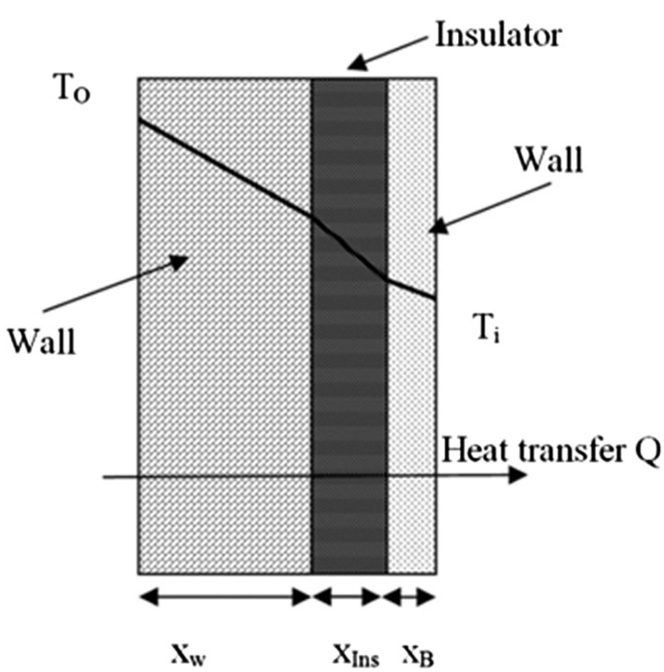


Fig. 1. Schematic drawing of the wall and the insulation layer.

simplified as below:

$$\frac{Q}{A} = -\frac{K(T_o - T_i)}{X} \quad (2)$$

The overall heat transfer per unit area from the ambient air to the wall surface can be described as the following [31]:

$$\frac{Q}{A} = UAT \quad (3)$$

where, U is the overall heat transfer coefficient of an insulated wall which can be expressed as:

$$U = \frac{1}{R_w + (X/K)_{ins}} \quad (4)$$

where, R_w is total thermal resistance of the composite wall. As mentioned earlier, the AC system operates during working hours (from Monday to Thursday, 8 h a day). Therefore, the annual energy required for cooling (E, kW h/m^2) can be demonstrated as a function of Annual Degree Demand Hours (ADH, hr) of the system and the heat transfer (Q, kW/m^2), can be concluded by the following equation:

$$E = \frac{ADH \times Q}{COP} \quad (5)$$

where, COP is the coefficient of performance for the system, ADH is equal to 1462 h [10]. Therefore, the annual energy consumption

Table 5
Input data.

Description	Unit	Values
Design temperature, outside air T_o	°C	37
Design temperature, inside air T_i	°C	21
Annual degree demand hours, ADH	Hours	1462
Life cycle period, N	Years	20
Wall Resistance, R_w	m^2 °C/kW	307
Thermal conductivity of air, K_{air}	W/m °C	0.02
COP of the AC system	–	2.93
Electricity tariff, C_e	US$/kW h	0.078

for cooling per unit area can be determined as:

$$\frac{E}{A} = \frac{ADH \times \Delta T}{(R_W + (X/K)_{ins}) \times COP} \tag{6}$$

4.2. Optimum insulation thickness and the cost benefit

Generally, the heat transfer is in direct relation with the area (A) and temperature gradient (ΔT), and it is in inverse relation with the insulation thickness (X). Furthermore, the insulation cost and its thermal conductivity plays an important role to define the optimum insulation thickness [34]. Mahlia et al. [28] has presented the correlation between thermal conductivity and the insulation thickness; the thermal conductivity and optimum insulation thickness present a non-linear relation (X_{opt}). They show that the localized electricity tariff rate, the insulation material cost, building lifetime, inflation rate, discount rate, and COP are the main parameters that determines the optimum insulation thickness [15]. The annual total cost of energy per unit area is derived as the following [10,28,35–37]:

$$C_t = \frac{E}{A} \times C_e \tag{7}$$

where, C_e is the localized electricity tariff rate. Combining Eqs. (6 and 7) gives:

$$C_t = \frac{ADH \times \Delta T \times C_e}{(R_W + (X/K)_{ins}) \times COP} \tag{8}$$

The present value of energy cost $P(C_t)$ is equal to the present worth factor (PWF) times the annual total cost of energy per unit area:

$$P(C_t) = PWF \times C_t \tag{9}$$

The Present Worth Factor (PWF) can be calculated with the following equation:

$$PWF = \frac{1}{r}\left[1 - \frac{1}{(1+r)^n}\right] \tag{10}$$

On the other hand, the total insulation cost (C_{ti}) is equal to the cost of insulation per unit volume (C_v) times the insulation thickness. In order to compare different insulation materials in economic aspect of view over the life cycle period (N) years, it is important to find the present value (PV) of the system [38]. The total PV is equal to the present value of energy cost plus the cost of insulation per unit volume:

$$PV = P(C_t) + C_{ti} \tag{11}$$

The summary of the required input data is presented in Table 5.

5. Applied method for investigating impact of thermal insulation on fuel consumption

Carbon and Hydrogen are considered as the main constituent of most fuels, followed by a small portion of sulphur. Combustion involves an oxidation reaction, in which the necessary oxygen is usually provided by air, a mixture of oxygen and nitrogen [39–41]. In Malaysia, natural gas is used as the main fuel for power generation [42]. The emission production (EM) is equal to emission factor (EF) multiplied by the amount of fuel consumed (FC). Therefore, the emission (p) due to use fuel (f) in the year (n) can be calculated with the following equation:

$$EM^p_{n,f} = EF^p_f \times FC_{n,f} \tag{12}$$

The potential emission production of each fuel based on Malaysian condition are summarized in Table 6 [23].

The amount of emission production for the next 20 years is predictable via three scenarios. The scenarios are tools for ordering perceptions about alternative future environments, and the result might not be an accurate picture of tomorrow, but may give a better decision about the future for policy makers. Regardless of how things can actually be, both the analyst and the decision maker will have a scenario that resembles a given future and will help researchers consider both possibilities and consequences of the future [43,44].

5.1. Scenario 1

In the first scenario, it is assumed that the proportion of each type of fuel for electricity generation in Malaysia is changing with the same pattern as the previous years. It is the simplest method to predict the emission for the future; however, it is not an accurate method.

5.2. Scenario 2

For the second scenario, the proportion of each fuel in the Malaysian power industry is assumed to change gradually from 2012 to 2031. The proposed trend is presented in Table 7.

5.3. Scenario 3

Because of some obstacles of using fossil fuels such as their ever increasing price, emission and their limited resources, the third scenario has focused on gradual substitution of renewable

Table 6
Emission factors (kg/kW h) used for estimating emission in power plants.

Fuel type	kg/kW h			
	CO_2	NO_x	SO_2	CO
Coal	1.18	0.0052	0.0139	0.0002
Natural gas	0.53	0.0009	0.0005	0.0005
Fuel oil	0.85	0.0025	0.0164	0.0002
Diesel	0.85	0.0025	0.0164	0.0002

Table 7
The share of fuel consumption for Malaysian power plants from 2012 to 2031.

Year	Coal (%)	NG (%)	Oil (%)	Diesel (%)	Hydro (%)
2015	30.0	58.0	0.7	1.0	10.0
2020	27.0	60.0	0.5	0.7	11.0
2025	25.0	62.0	0.5	0.0	12.0
2031	23.0	65.0	0.0	0.0	14.0

powers to the traditional fossil fuel sources. However, because of the high initial costs of installation, the share of this type of power plants is still lower than the conventional power plants [24,45,46]. A survey conducted by Masjuki et al. [3] shows several benefits of the gradual fuel substitution for electricity generation from fossil fuel to renewable energy resources.

The third scenario assumes that the percentage of electricity generation based on fuel types will change over the time. The proposed change in the share of fuel consumption is according to the Malaysian policy to increase the renewable power plants (Table 8) [47]. Comparing Tables 7 and 8 reveals that in the current scenario, Malaysia would increase the share of renewable power plants such as hydro, solar, wind, geothermal and photovoltaic plants rather than just increase in hydro.

5.4. Method of data estimation

Some data are available, but others have to be estimated. There are several methods for estimating data, the one that is widely used is polynomial curve fitting. This method tries to describe the relationship between a variable (X) as the function of available data and a response (Y) that seeks to find a smooth curve for the best fit of data. Mathematically, a polynomial of order k in X can be expressed in the following equation form Refs. [48,49]:

$$Y = C_0 + C_1X + C_2X^2 + \cdots + C_kX^k \tag{13}$$

Table 8
The share of fuel consumption for Malaysian power plants from 2012 to 2031.

Year	Coal (%)	NG (%)	Oil (%)	Diesel (%)	Renewable power plants (%)
2015	30.0	56	0.7	1.0	13.0
2020	20.0	56.0	0.5	0.7	24.0
2025	12.0	55.0	0.5	0.0	34.0
2031	0.0	54.0	0.0	0.0	46.0

6. An application of utilizing thermal insulation with optimum thickness

6.1. Optimum thickness

By applying the above mentioned formulations to the various types of insulation materials that are available in Malaysian market, the optimum thickness can be evaluated. The results for fibreglass urethane are presented in Fig. 2, where the optimum thickness of 2.2 cm is obtained. Fig. 3 shows the results for Perlit, its optimum thickness was found to be 5 cm.

The optimum thickness of extruded polystyrene and fibreglass (rigid) materials are also calculated similarly, and the results are 2.6 and 2 cm, respectively. The effect of different insulation material on the total cost is presented in Fig. 4.

The results indicate that as the insulation thickness increases, the energy consumption is reduced, and consequently, the emission level and energy cost decreases. On the other hand, the insulation initial cost increased significantly with the increasing thickness. The figure shows that this increment occurred linearly. Therefore, the relation between total cost and insulation thickness will be a non-linear relation. It can be observed that by increasing the thickness, the total cost would decrease until it reaches a minimum level, and from there it will have an upward

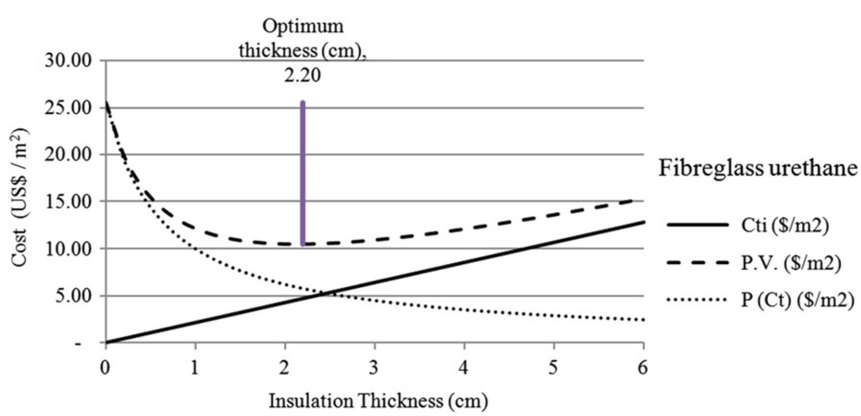


Fig. 2. Effect of insulation thickness on cost (fibreglass urethane).

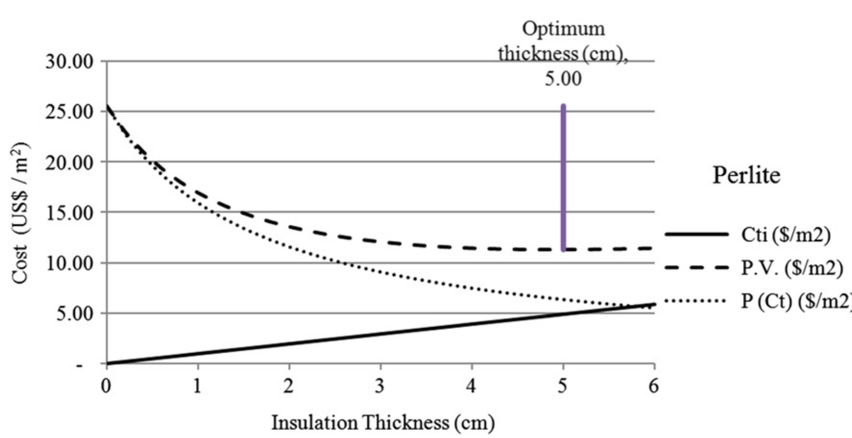


Fig. 3. Effect of insulation thickness on cost (Perlite).

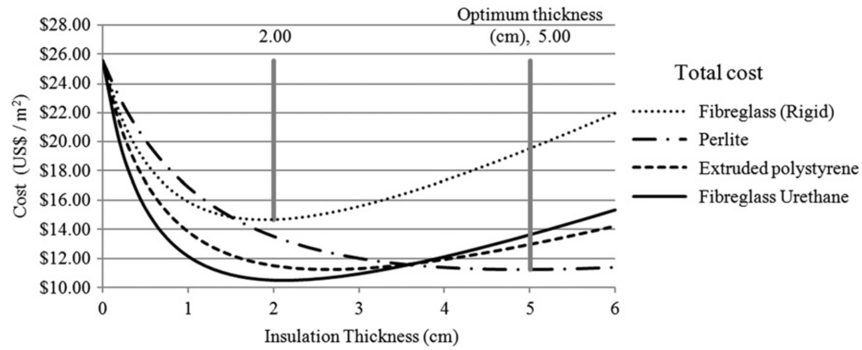


Fig. 4. Effect of different insulation materials on annual total cost.

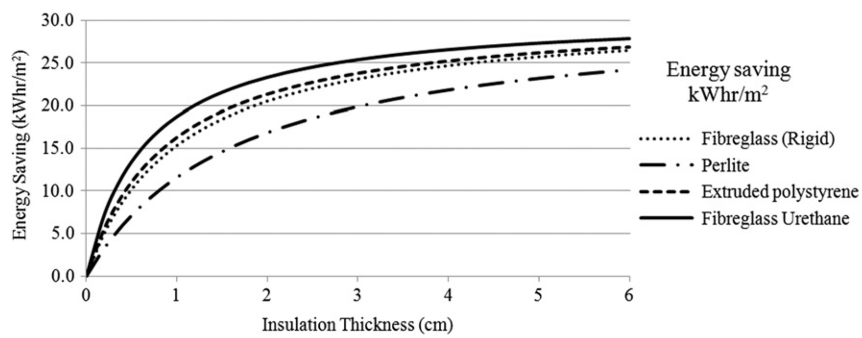


Fig. 5. Effect of different insulation materials on annual energy saving.

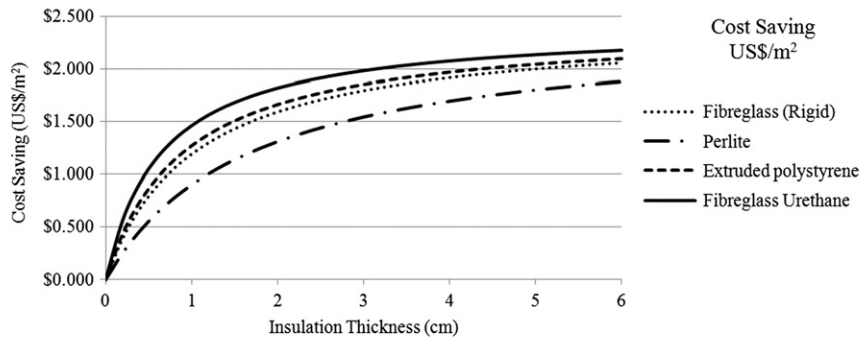


Fig. 6. Effect of different insulation materials on annual cost saving.

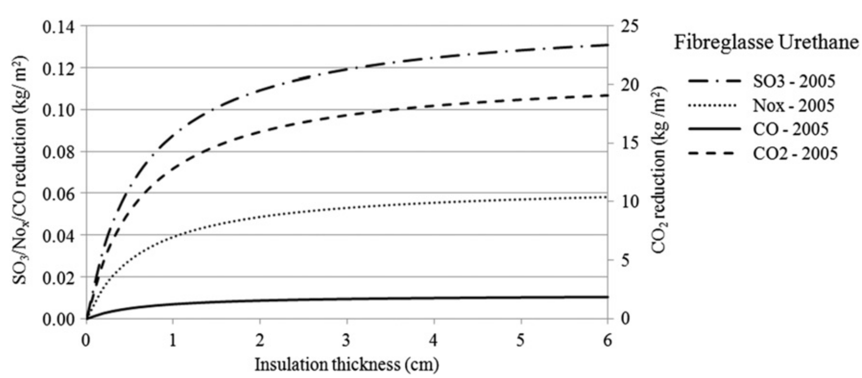


Fig. 7. Effect of insulation thickness on emission reduction per year (fibreglass urethane).

trend. This minimum point shows the optimum insulation thickness, where the total cost is at the lowest level. This trend was observed in all of the studied materials in Fig. 4.

Fig. 5 shows the annual energy saving of four different insulation materials. The table shows that Fiberglass Urethane has the highest level of energy saving potential while Perlite has the lowest. The results show that the energy saving at optimum thicknesses of Fiberglass (rigid), Perlite, extruded polystyrene and Fiberglass-urethane are 20.5, 23.2, 23 and 23.9 kW h/m^2, respectively.

The effect of different materials on total annual cost saving per meter square is presented in Fig. 6. The results show that fibreglass–urethane is the most cost effective material with around 1.86US$/m2 savings. Again, Perlite has the lowest cost saving level. The cost saving at optimum thicknesses of Fiberglass

(rigid), Perlite and extruded polystyrene are 1.59, 1.80 and 1.79US$/m^2, respectively. Although Perlite has the lowest overall cost savings, but in its optimum thickness, it has almost the same cost saving as Fiberglass-urethane.

6.2. Emission reduction

Thermal insulation can reduce the total building energy consumption and consequently reduce CO_2 emissions. In this paper, the effect of applying different insulation materials on the outside walls of a building on emission reduction is evaluated. The results indicated that by increasing the insulation thickness, the fuel consumption and the emission level decreased. This can be observed in Fig. 7 where the effect of increasing fibreglass–urethane thickness was plotted for different particles. It is clear that CO_2 has the highest amount of emission.

In view of the fact that CO_2 is considered to be the main pollutant that contributes to the greenhouse effect, this paper focused more on CO_2 emission reduction.

6.2.1. Results for future emission production prediction based on scenario 1

Fig. 8 shows the effect of different insulation materials on their optimum thickness on CO_2 emission pattern in Malaysia for the next 20 years. It can be observed that fibreglass–urethane has the highest emission reduction rate while fibreglass (rigid) has the

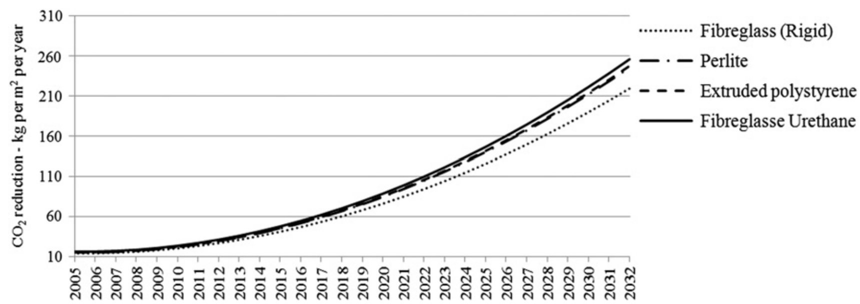


Fig. 8. Effect of different insulation materials on their optimum thickness on CO_2 reduction for the period of 20 years.

Table 9
CO_2 productions for different insulators on their optimum thickness.

Year	Fiberglass uritain	Extruded polystiren	Perlite	Fiberglass rigid
2012	16.67	16.05	16.19	14.30
2013	16.73	16.11	16.25	14.36
2014	16.77	16.15	16.29	14.39
2015	16.14	15.54	15.68	13.85
2016	16.72	16.10	16.24	14.35
2017	16.68	16.06	16.20	14.31
2018	16.60	15.99	16.13	14.25
2019	16.50	15.90	16.03	14.17
2020	15.45	14.88	15.01	13.26
2021	16.23	15.63	15.76	13.93
2022	16.05	15.45	15.59	13.77
2023	15.84	15.25	15.39	13.59
2024	15.60	15.03	15.16	13.39
2025	14.99	14.44	14.57	12.87
2026	14.95	14.40	14.52	12.83
2027	14.63	14.09	14.22	12.56
2028	14.29	13.76	13.88	12.27
2029	13.92	13.41	13.52	11.95
2030	13.52	13.02	13.14	11.61
2031	13.10	12.61	12.72	11.24

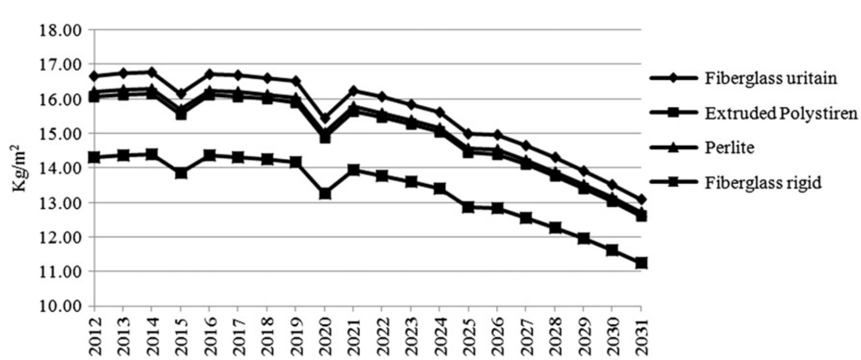


Fig. 9. CO_2 productions prediction for the next 20 years for different insulators on their optimum thickness.

lowest rate. The future emission production rate is predicted using available emission production data of the years 2005 to 2008. As mentioned earlier, this method has a low level of certainty. It is apparent from the findings that the emission production rate increased drastically for the next 20 years.

6.2.2. Results for future emission production prediction based on scenario 2

The results obtained from the analysis of CO_2 emission production based on the second scenario are summarized in Table 9 and are graphically presented in Fig. 9. In the second scenario, it is assumed that the proportion of each fuel in Malaysian power industry will change gradually from 2012 to 2031.

The result shows an overall decreasing trend for the next 20 years, which is mainly caused by the emission reduction policies that are followed by the Malaysian main electricity providers. The analytical review on the available data from the years 2005, to 2008 shows that the CO_2 production level in the year 2008 has decreased slightly. The results obtained based on the second scenario contradicts the first assumption. However, the predicted trend is more realistic.

The emission production fluctuations for CO, NOx and SO_2 are also calculated for both prediction scenarios, and the results show the same trend as CO_2.

6.2.3. Results for future emission production prediction based on scenario 3

The CO_2 production values based on third scenario has been tabulated and plotted in Table 10 and Fig. 10 for different thermal insulators on their optimum thickness. As the results shows there will be a sudden depletion in the production of carbon dioxide according to the third scenario. Fig. 9 shows that the emission production related to fibber glass uritain will be decreased from 16.7 (kg/m^2) in 2012 to 7.3 (kg/m^2) in the year 2031. Comparing these results to the results obtained in scenario 2 shows that investment on different renewable energies resources can have a more promising results rather than just focusing on the hydro power.

7. Conclusions

The cost benefits and emission reduction effects by applying the optimum insulation thickness on external walls of Malaysian

Table 10
CO_2 productions for different insulators on their optimum thickness based on scenario 3.

Year	Fiberglass uritain	Extruded polystiren	Perlite	Fiberglass rigid
2012	16.67	16.05	16.19	14.30
2013	16.44	15.83	15.97	14.11
2014	15.99	15.40	15.53	13.73
2015	15.89	15.30	15.43	13.64
2016	14.91	14.36	14.49	12.80
2017	14.45	13.92	14.04	12.41
2018	13.99	13.47	13.59	12.01
2019	13.52	13.02	13.13	11.60
2020	12.84	12.37	12.47	11.02
2021	12.56	12.10	12.21	10.78
2022	12.08	11.63	11.74	10.37
2023	11.59	11.17	11.26	9.95
2024	11.10	10.69	10.79	9.53
2025	10.32	9.94	10.02	8.86
2026	9.88	9.51	9.60	8.48
2027	9.37	9.03	9.11	8.05
2028	8.86	8.54	8.61	7.61
2029	8.35	8.04	8.11	7.17
2030	7.83	7.54	7.61	6.72
2031	7.31	7.04	7.10	6.28

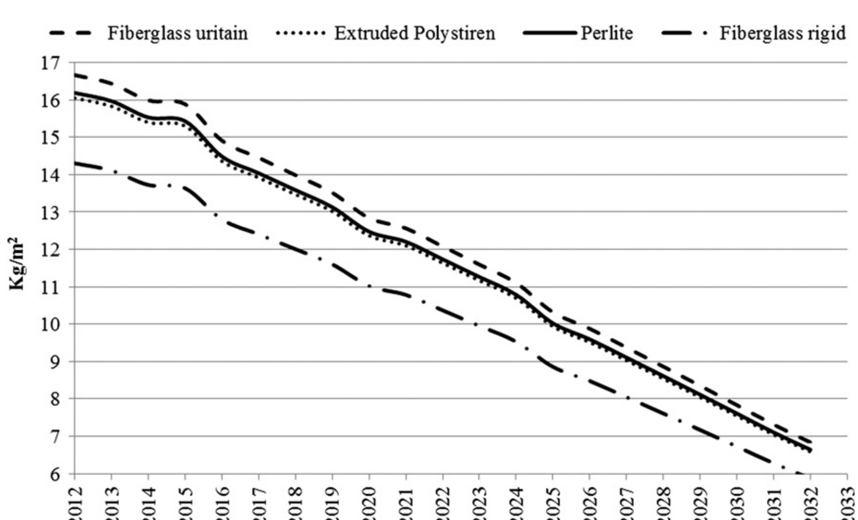


Fig. 10. CO_2 productions prediction for the next 20 years for different insulators on their optimum thickness.

building was conducted in this research. The analysis focused on the potential emission reduction level in Malaysia. The fuel consumption and emission reductions are calculated using the energy consumption caused by heat transfer through the building walls. The overall results shows that using optimized thickness for proper insulation will significantly reduce the electricity consumption and consequently, reduce the emission production level. Although increasing the insulation thickness increases the capital costs, but reduces the energy consumption as well, making it economically feasible. The findings show that an optimum thickness exists in a way that the total energy cost corresponding to that specific thickness is at it lowest. The current study found that 2.2 cm of fibreglass–urethane results in the savings of around 1.86US$/m^2, making it the most suitable insulation material. While 2 cm of fiberglass (rigid) reduces the total cost by 1.59US$/m^2, which is approximately 20% lower than fibreglass–urethane.

The insulation material, at its optimum thickness, reduces the fuel consumption significantly and consequently, simultaneously decreasing the exhaust emissions. The emission production level for the next 20 years is predicted via three different scenarios. The results of the first scenario were found in contrast with expectations, which is mainly due to the high level of uncertainties and assumptions of the proposed trend. The results of the second scenario show a more-realistic trend for the emission production level for the next 20 years in Malaysia. The results show a downward trend due to the emission reduction policies of the Malaysian main power generator company. The third scenario reveals that an increase in the contribution of renewable power plants on one hand, and phasing out of the conventional thermal coal plants on the other will substantially lead to a reduction in the emission of CO_2.

The results of the present survey can be used as a useful guide for engineers to select the proper insulation material with a proper thickness, and also can provide a clear picture for policy makers concerning the future of the planet and environment.

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